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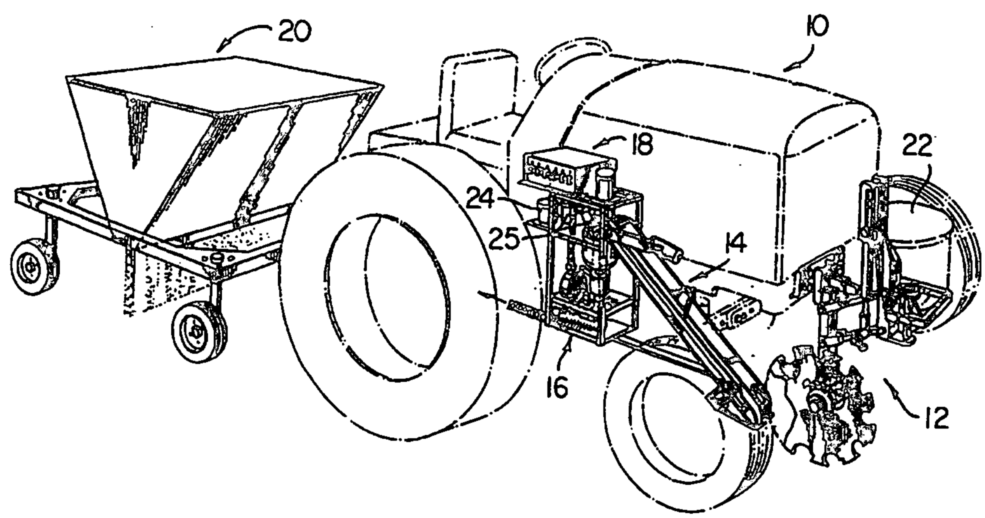

(57) Abstract

An improved apparatus for measuring soil nutrient concentration or pH level in soil samples of a known size is used in combination with a soil sampling and transport subassembly (12, 14) mounted on a farm vehicle (10) for on the go measurement of soil nutrient or pH levels in a field. A controller (18) is provided to sequence the operation of the various subassemblies and the system includes provision of a fertilizer applicator (20) automatically having its fertilizer application rate controlled based upon the measured soil nutrient concentrations or pH levels and ground speed of the farm vehicle (10).

SOIL NUTRIENT MONITORING SYSTEM

Field of the Invention

The invention generally relates to a method and apparatus for measuring nutrient or pH levels in soil, and a method to optimize fertilizer usage in agricultural applications.

Background of the Invention

A large portion of expenditures faced by agricultural producers relates to the addition of fertilizer to soil in agricultural fields.

It is known to assess fertilizer application rates for a given field through remote analysis of soil samples collected from the field. The samples are analyzed to determine nutrient and/or pH levels in the field to arrive at a uniform recommended fertilizer application rate for the field. However, nutrient and pH levels vary over a field, and over time. Accordingly, sampling with remote analysis to arrive at a uniform fertilizer application rate often results in over fertilization or under fertilization of some portions of the field. Such inappropriate fertilizer application contributes to environmental problems since excess chemicals from the fertilizer are leached into ground water. Further, inappropriate application of fertilizer unnecessarily raises crop production costs and results in non-uniform crop yields.

Fertilizer application rate recommendations in North America have traditionally been based on determination of soil organic matter content (e.g. the amount of various nutrients, such as nitrogen and potassium) and pH. Soil pH relates to the relative acidity or basicity of the soil, and is measured by determining the hydronium ion activity in a solution of soil and extractant. Soil pH influences crop production in many ways including the availability of nutrients and

toxic substances to crops and the activities of microbial populations and certain pesticides.

Various water-soluble ions (e.g. the water soluble nitrate ion) are the predominant form in which various nutrients (e.g. nitrogen) are available to many plants. In light of that fact, soil nutrient ion levels may be directly measured as an indication of soil nutrient supplying potential. The advantage of direct measurement of various nutrient ion levels as compared to organic matter levels is that various nutrient ions are the predominant form in which various nutrients are available to plants whereas organic matter is not. However, the disadvantage is that various nutrient ion levels (and pH levels) are more transient, therefore making it desirable to measure nutrient ion levels (and pH) in as close proximity both spatially and in time to the fertilizer application as possible.

One effective means for measuring nutrient or pH levels in soil samples is through the use of electro-chemical ion-selective electrodes. The electrode is brought into contact with a solution prepared by adding a controlled mass of extractant to a controlled mass of soil and passing the mixture through a filter to obtain an extract solution. The nutrient ion level or the pH in the soil is then measured by comparison of electrical potential of the ion-selective electrode and a reference electrode placed in the extract solution. Existing apparatus for carrying out such analysis include an extraction chamber, filtration means and a chamber housing the electrodes. The electrodes are kept in contact with the solution for a relatively long period of time (i.e. two minutes or more) to obtain a final nutrient ion or pH level. Use of such apparatus is relatively slow and labour intensive due to the need to carefully monitor the system for blockages, and the need to carefully monitor calibration of the electrodes.

As noted above, measuring nutrient ion concentration or pH in soil is advantageously done in as close proximity both spatially and in time to the application of fertilizer as possible. Accordingly, the need for "on the go" farm vehicle mounted measurement apparatus for control of fertilizer applicators has been recognized and various apparatus have been proposed.

For instance, in his thesis entitled "Automated Field Monitoring of Soil Nitrate levels", dated September 1990, J.F. Adsett proposed direct measurement of nitrate levels in a field by use of nitrate ion-selective electrodes in a farm vehicle mounted unit for "on the go" measurement of nitrate levels. This procedure utilized a conventional chainsaw bar and chain to collect soil samples which were delivered to a nitrate extractor. The extractor included a turntable having a soil sample holder for metering a soil sample. The sample holder was moved on the turntable from its soil receiving position to a nitrate extraction position and then to a sample holder cleaning position. At the extraction station, an extractant was added to the soil sample and a vacuum was applied below the sample to draw the soil extract through a screen into a sump. The extract was then pumped through a flow cell for nitrate measurement using an ion-selective electrode. Problems were encountered due to the number of moving parts and friction between the soil and rotating parts, varying performance depending upon soil sample consistency, leaking of extractant from the soil sample holder and clogging of the system. Further, the length of time necessary to obtain reliable measurements was too long for commercial usage. Accordingly, the need for a commercially viable system remained.

The present invention attempts to overcome the problems in prior apparatus and methods for measurement

of soil nitrate levels, levels of other nutrient ions (e.g. potassium ions) or pH in agricultural fields. Accordingly, it is an object of the present invention to provide an improved apparatus for measuring nutrient ions or pH in a soil sample, an improved process and apparatus for mapping nutrient ion or pH levels in agricultural fields, and an improved process and apparatus for "on the go" control of fertilizer application, including an improved method and apparatus mounted on a farm vehicle, for obtaining soil samples from fields and measuring nutrient ion or pH levels therein.

Summary of the Invention

The present invention provides a soil nutrient or pH monitoring apparatus for the measurement of nutrient or pH levels in soil samples of a given mass comprising:

(a) a container having at least one opening for serially receiving soil samples and a discharge opening;

(b) a valve selectively operable to open and close the discharge opening;

(c) at least one nozzle for addition of extractant fluid to a soil sample in the container and for addition of cleaning fluid when the soil sample is discharged;

(d) an electro-chemical nutrient or hydronium ion-selective electrode and a reference electrode positioned in the container such that a sufficient portion of each electrode contacts the extract solution formed upon addition of the extractant fluid to the soil sample; and

(e) a controller for controlling the quantity of extractant fluid added to the container so as to ensure proper fluid to soil ratio, for determining

the measurement time required to measure the nutrient or pH level of the soil sample, for calculating and recording the nutrient or pH level from the electrodes after the measurement time, and for actuating the valve and nozzle to empty and clean the container after the measurement is completed.

The present invention also provides a process for rapidly measuring nutrient or pH levels in soil comprising:

(a) Determining a minimum acceptable measurement time by:
   (i) Measuring the nutrient or pH level in a reference soil sample at several time intervals over a sufficiently long period of time so that substantially the total nutrient or pH level has been measured by the last interval;
   (ii) Calculating the percentage of the nutrient or pH level measured at each time interval by dividing the nutrient or pH level at each time interval by the total nutrient or pH level measured at the last interval; and
   (iii) Identifying the minimum acceptable time by determining the earliest time at which the rate of increase in the percentage of the nutrient or pH level measured becomes stable.

(b) Determining the percent total nutrient or pH constant by dividing the total nutrient or pH level at the last interval by the nutrient or pH level at the minimum acceptable measurement time;

(c) Serially measuring the nutrient or pH level in a plurality of test soil samples at the minimum acceptable measurement time; and

(d) Multiplying each measurement obtained in (c) by the percent total nutrient or pH constant.

Furthermore, the present invention provides a farm vehicle mounted soil nutrient or pH monitoring apparatus for mapping nutrient or pH levels in soil in a field as the farm vehicle traverses the field comprising:

(a) a soil sampling subassembly;

(b) a soil transport subassembly;

(c) a nutrient or pH measurement subassembly; and

(d) a control subassembly

wherein the soil sampling subassembly and soil transport subassembly sequentially deliver powdered soil samples of predetermined volume to the nutrient or pH measurement subassembly, the nutrient concentration or pH level of each sample is measured in the nutrient or pH measurement subassembly, and the control subassembly sequences the operation of the other subassemblies and sequentially stores the measured concentrations.

And finally, the present invention provides a farm vehicle mounted apparatus for obtaining soil samples as said farm vehicle traverses a field comprising:

(a) a soil sampling subassembly including a blade mounted on said farm vehicle for rotation about a generally horizontal axis with the blade extending into the topsoil to produce a powdered spray of soil particles exiting generally tangentially from said blade upon rotation;

(b) a soil sample transport subassembly including a receiving pocket of predetermined volume for receiving a soil sample, a conveyor for transporting the pocket from a first position where

the pocket is maintained in said spray of soil particles to a second position where said soil sample is substantially completely discharged into a receptacle; and

(c) a controller for automatically controlling the conveyor to maintain the pocket at the first position for a predetermined duration.

The invention will now be described, by way of example, through reference to the Figures attached hereto.

Brief Description of the Drawings

Figure 1 is a pictorial representation of a farm vehicle having soil sampling, soil transport, nutrient or pH measurement, control and fertilizer applicator subassemblies mounted thereon.

Figure 2 is a side view of a soil sampling subassembly.

Figure 3 is a front view of the soil sampling subassembly.

Figure 4 is a side view of the soil transport subassembly and nutrient or pH measurement subassembly.

Figure 5 portrays a normalized curve of percent final nitrate level versus measurement time for a nitrate ion-selective electrode in a particular soil.

Figure 6 is a schematic representation of the control circuits for the nutrient or Ph measurement and fertilizer application system.

Figure 7 is a schematic representation of the nutrient or pH measurement system of the invention.

Figure 8 is a schematic representation of the calibration routine of the nutrient or pH measurement system.

Detailed Description

In light of the transient nature of various nutrients and pH in a given field, it is desirable to obtain samples from a given field on a generally grid-like basis so that the nutrient or pH levels of the soil in the field may be "mapped".

One embodiment of the present invention provides a farm vehicle mounted apparatus for measuring a soil nutrient (such as nitrogen or potassium) or pH as the farm vehicle traverses the field. The apparatus may generally be mounted on the farm vehicle 10, such as a tractor, in any suitable manner. Alternatively, the apparatus may generally be mounted on farm equipment towed by the farm vehicle 10. The subassemblies of the apparatus include a soil sampling subassembly 12, a soil transport subassembly 14, a nutrient or pH subassembly 16, and a control subassembly 18. The apparatus also includes an extractant fluid tank 22 and calibration solution tanks 24, 25 as well as various hoses, valves, motors, pumps, etc. (not all shown) required for operation of the various subassemblies of the invention, all as described below. The nutrient or hydronium ion concentration of each sample is measured in the nutrient or pH measurement subassembly 16, and the control subassembly 18 sequences the operation of the nutrient or pH subassembly 16 and sequentially stores the measured concentrations or pH levels. Further, the control subassembly 18 may be utilized to record ground speed of the farm vehicle and sample times for basic grid mapping. As will be recognized by those skilled in the art, a more advanced mapping system may be utilized with remote directional signals, a (Global Positioning System) GPS receiver or other means for tracking the exact position of the farm vehicle in the field.

Referring to Figure 1, another embodiment of the present invention is a farm vehicle mounted apparatus and system for "on the go" control of the

application of fertilizer having automated means for ~~taking soil samples, measuring nutrient concentration or~~ pH level in the samples and controlling the application rate of fertilizer based upon ground speed of the farm vehicle and the measured nutrient concentration or pH level. The apparatus may generally be mounted on the farm vehicle 10, such as a tractor, in any suitable manner. Alternatively the apparatus may be mounted on farm equipment being towed by the farm vehicle. The subassemblies of the apparatus include a soil sampling subassembly 12, a soil transport subassembly 14, a nutrient or pH measurement subassembly 16, a control subassembly 18 and a fertilizer applicator subassembly 20. The apparatus also includes an extractant fluid tank 22 and calibration solution tanks 24, 25 as well as various hoses, valves, motors, pumps, etc. (not all shown) required for operation of the various subassemblies of the invention, all as described below.

The soil sampling subassembly 12 generally consists of a blade which may be a circular saw blade of the type generally used in sawmills. The blade is mounted on the farm vehicle such that it floats on the soil surface with the blade extending into the soil a predetermined distance (normally 5-15 cm which will vary depending upon the particular soil type, crop and field conditions) and such that its axis of rotation is generally perpendicular to the primary direction of travel of the farm vehicle. The direction of rotation of the blade will normally be the same direction as that of the farm vehicle wheels so that the spray of soil created by the cutting blade is directed rearwardly of the blade.

Any suitable means for rotating the cutting blade, such as fuel, hydraulic or electric motors or actuation may be utilized. Similarly, any suitable mounting means for mounting the soil sample subassembly

may be utilized within the general requirements noted above.

In a preferred embodiment, referring to Figures 2 and 3, the soil sampling subassembly, generally designated 12 includes a circular blade 26 having soil displacing cutting surfaces, in this case serrations 28. The circular blade 26 is mounted on drive shaft 30 of a hydraulic drive motor 32. The hydraulic drive motor 32 is mounted in a housing 34 which includes a skid 36 with may include a directional stability rod 37 on its lower end. The hydraulic drive motor 32 is coupled to the farm vehicle's hydraulic system through hoses 38 and is driven by the hydraulic system of the farm vehicle 10.

The housing 34 is mounted on a generally vertical support member 40. The vertical support member 40 is in turn pivotally connected to the ends of two support bars 42, 44 by attachment members 46, 48. The opposite ends of the support bars 42, 44 are pivotally connected to vertical support member 50 by bolts 52, 54. The connection points between the support member 40, support bars 42, 44 and vertical support member 50 form a parallelogram generally designated 56. The support member 50 is in turn mounted in any suitable known manner on the farm vehicle 10 such that the axis of rotation of the blade 26 is generally perpendicular to the primary direction of travel of the farm vehicle. Pivot means comprising a joint and pin 58 and connecting members 60, 62 may be utilized. It has been found that it is preferable to lock the joint, in this case with locking screws 63, so that it is held in a suitable fixed position when the soil sampling subassembly 12 is mounted on the front of the farm vehicle. If the soil sampling subassembly is trailed, preferably the pivot means 58, 60, 62 include a torsion spring biasing the blade 26 to a position with its axis of rotation

perpendicular to the primary direction of travel of the farm vehicle but allowing for breakaway protection to minimize blade damage should obstructions be encountered.

A hydraulic ram 66 is mounted on the support member 50 by sliding engagement of the piston end 67 of the ram 66 in the slot 69 with the external end of the piston rod 68 connected to the support bar 42. Hydraulic hoses 70 are supplied with hydraulic fluid from the farm vehicle 10 and attached to the hydraulic ram 66. The blade 26, motor 32 and housing 34 may be raised and lowered by operation of hydraulic control means (not shown) engaged with the hoses 70.

When the soil sampling subassembly 12 is to be operated, the housing 34 is lowered until the skid 36 floatingly supports the weight of the housing 34, etc. on the field's surface. Suitable means may be provided to allow for adjustment of the height of the housing 34 relative to the skid 36 so as to vary sampling depth (i.e. the cutting depth of the blade 26). In the preferred embodiment, the adjustment means 72 comprise locking nuts 74 which lock at variable positions along channel 76, but any suitable means may be used.

In operation, the blade 26 is generally maintained at the predetermined depth by gravity acting on the soil sampling subassembly 12 to keep the skid 36 in contact with the soil surface. The parallelogram 56, in combination with the piston end of the hydraulic ram 66 sliding vertically in slot 69 of support member 50, allows the soil sampling subassembly 12 to float and to follow ground undulations. Of course, any suitable means may be provided for raising and lowering the soil sample subassembly and for mounting it on the farm vehicle. For instance, an electric actuator could be used instead of the ram 66. However, preferably, whatever means are used will allow the blade 26 to float

and follow ground undulations to minimize damage to the blade should obstructions, such as rocks in the soil, be encountered.

When the soil sampling subassembly is in operation, rotation of the blade 26 in the topsoil produces a powdered spray of soil particles exiting generally tangentially from the blade 26.

Generally, as noted below, soil to extractant mass ratios must be controlled. Accordingly, it is necessary to utilize soil samples for which the mass is known. Work undertaken by the inventors has shown that volume/mass ratio of various types of common agricultural soil differ very little when the soil is reduced to a fine powder so long as there is no recompaction. In light of that fact, it is possible to utilize a system wherein soil sample size is controlled by controlling volume thereof.

Alternatively, means can be used to weigh the soil sample prior to its delivery to the extraction chamber.

Referring again to Figure 1, the soil sample transport subassembly 14 generally consists of a conveyor mounted on the farm vehicle 10 so as to be centred in the spray of soil particles created by operation of the soil sample subassembly 12. The soil transport subassembly includes a receiving pocket of predetermined volume which is filled from the spray of soil and which is adapted to fully discharge that volume of soil into a receptacle when moved to the correct position by the conveyor.

Referring to Figure 4, in an illustrated embodiment, the soil transport subassembly generally designated 14 includes a continuous belt 100 mounted on a conventional conveyor support frame 102 having conveyor rollers 104, 105. The belt is driven by a motor 106 and pulley 108 which drive roller 104.

The conveyor support frame 102, motor 106 and pulley 108 are pivotally mounted on a common frame 110 with the nutrient or pH measurement subassembly generally designated 16. Pivotal mounting of the support frame 102 on the frame 110 allows movement of the support frame 102 to avoid damage from obstructions protruding from the surface of the field. Any suitable pivotal mounting means may be utilized, such as a pivotal U frame 113 attached to member 111 of frame 110 allowing for vertical displacement of the support frame 102 in the U frame 113 and a mounting means 117, which provides a pivotal mount. A skid 115 may also be provided on the lower end of the support frame 102 to facilitate the conveyor riding over any obstructions.

The mounting frame 110 is mounted to the farm vehicle 10 in any suitable manner as to ensure that the top of the lower end of the conveyor is centred in the spray of soil created by the soil sampling subassembly 12.

The belt 100 includes an integral receiving pocket 112 which is formed by any suitable means. Preferably, the sides and bottom are smooth and are lined with a material to which the soil will not adhere. The pocket 112 forms a sample cup of predetermined volume. A scraper 114 is mounted above the belt such that it scrapes the surface of the belt 100 across its entire width. The scraper 114 may be made of any suitable material and may be mounted in any suitable manner so as to remove excess soil to ensure that the volume is limited to the preset volume, is not compressed in the pocket 112 and that all soil is removed from the surface of the belt. It has been found that a square edge on the scraper 114, with a 45° angle provides good results.

In the preferred embodiment, a notch 116 is positioned on the belt so as to engage an electric

switch 118 which is mounted adjacent the belt 100 on the support frame 102. The electric switch 118 is electrically connected to the control subassembly 18 (Figure 1) and is utilized to maintain the pocket 112 in the spray of soil from the soil sampling subassembly 12 for a sufficient period of time to allow the pocket 112 to be filled with soil.

During operation of the soil transport subassembly 14, the belt 100 rotates about the rollers 104, 105. When the electric switch 118 is engaged by the notch 116, the electric motor is turned off and the belt is positioned such that the pocket 112 is in the spray of the ground soil exiting from the soil sampling subassembly 12. After a predetermined time, the electric motor is turned on by the control subassembly 18 (as described below) and the belt 100 commences rotation. As the belt 100 and pocket 112 pass under the scraper 114 all excess soil from the belt and pocket 112 is removed. As the pocket 112 passes around the roller 104, the dimensions of the pocket are varied and the soil is loosened from the sides and bottom thereof such that substantially all of the soil in the pocket 112 is discharged into a receptacle located under the roller 104. In the embodiment shown in Figure 4, the receptacle is the container 150 of the nutrient or pH measurement subassembly 16.

Referring again to Figure 1, the nutrient or pH measurement subassembly 16 generally consists of a container having electrodes mounted in it, the container being adapted to receive a soil sample and extraction fluid. The soil sample and extraction fluid are mixed in the container and nutrient ion or hydronium ion concentration is measured for a predetermined time period, after which the container is emptied and cleaned so as to be ready for another measurement. Electronic circuits and solenoids are provided to control addition

and discharge of fluids from the container to provide for automated operation of the subassembly.

Referring to Figure 4, in the illustrated embodiment, the nutrient or pH measurement subassembly, generally designated 16 is mounted on a common frame 110 with the soil transport subassembly 14, the frame 110 being adapted to be mounted on the farm vehicle 10 in any suitable manner. However, the nutrient or pH measurement subassembly 16 may also be used as a stand alone unit.

In the illustrated embodiment, the soil samples to be measured are deposited in the container 150 from the pocket 112 of the soil transport subassembly 14 as described above. However, other means including manual deposit of soil samples can be utilized, particularly in stand alone applications.

The container 150 has an open top 152 through which the soil sample and extractant fluid are placed in the container. The bottom of the container includes an opening 154 and a valve 156 (operable through solenoid 157) that is mounted on the bottom of the container and selectively operable to open and close the opening 154. A drain pipe 158 is connected to the discharge of valve 156 for disposal of fluids and soil particles from the container.

Extractant fluid, which will typically be distilled or deionized water (which, depending on the soil type, may include additives such as ammonium sulphate which acts as an ionic strength adjuster) is pumped from the extractant fluid tank 22 (see Figure 1) through extractant hoses 160, 162 by means of an electric water pump 164. The hose 162 is attached to a pressure gauge 166 which is in turn attached to a solenoid operated valve 168 connected to nozzles 170 which are directed into the container 150. In the preferred embodiment, spray nozzles are used. An

impeller 172 is located in the container 150 and is driven by an electrical mixer motor 174 and impeller shaft 176.

Generally, the mass ratio of soil to extractant will be in the range of 1:3 to 1:5. Since the ion-selective electrode will respond faster to high concentrations of nutrient ions or hydronium ions, a high soil to extractant ratio should be used for soils having low nutrient concentration or low pH.

A nutrient ion-selective electrode or hydronium ion-selective electrode 178 is mounted in the container and positioned so as to ensure that the ion sensing portion (a plastic organophilic membrane) is below a predetermined fill level in the container 150. The electrodes generally include a sensing module in the tip of the electrode, and it is only necessary to ensure that the tip is below the fill level. A reference electrode (not shown) is similarly positioned in the container 150. It should be ensured that the electrodes do not touch the sides of the container 150 so as to allow the extractant fluid/soil solution to flow unhindered around and between the electrodes. Alternatively, a nutrient or hydronium ion-selective electrode with a built in reference can be used instead of two electrodes.

Various nutrient ion-selective electrodes and pH electrodes and reference electrodes are commercially available. For instance, the Orion* model 93-07 nitrate electrode and the Orion* model 90-02 sleeve type Ag/AgCl double junction reference electrode with ammonium sulphate (0.04 M) as the outer filling solution may be utilized. Alternatively, the Orion* Model 9707 Ion Plus combination electrode (with built in reference) can be used to measure nitrate ion levels.

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The nutrient or pH measurement subassembly 16 also includes calibration solution tanks 24, 25 (see Figure 1) and suitable calibration solution hoses 180, 182 and pumps 184, 186 for supplying a specific volume of two different calibration fluids to the container for electrode calibration as described below.

When the nutrient or pH measurement subassembly 16 is to be used the nutrient or pH electrode 178 and reference electrode are mounted in the container and electrically connected to the control subassembly 18 which measures the electrode potential. Various meters for measuring electrode potential are commercially available including meters which directly calculate nutrient concentration or pH level. In the illustrated embodiment, meter circuitry has been built into the controller.

It has been found that reliable measurements of nutrient ion concentrations or pH can be obtained very quickly (typically 4-6 seconds) with a nutrient ion or pH measuring apparatuses as described herein. Specifically, soil nutrient ion measurements or pH by ion-selective electrodes exhibit similar response time curves for different soil types over time. The differences between the response time curves for different soil types are primarily due to different rates of soil nutrient ion release or hydronium ion release (for pH measurement) to the extraction solution. Agitation of the extraction solution and the soil sample promotes soil nutrient ion or hydronium ion extraction. Agitation may be facilitated by the setting of nozzle direction for adding the extractant. Alternatively, or in addition, an impeller or other agitation means may be included in the container. Due to the similarity of the response time curves for nutrient ion or hydronium ion extraction in different soil types, it is possible to undertake initial calibration measurements on the soil

which is being sampled to calculate a minimum measuring time. Such soil calibration measurements usually require at least a two minute extraction time in the container. By evaluating the stability of the signal received from the electrodes, the time required to reach a portion of the response time curve where increase over time becomes stable may be calculated. A minimum time is then utilized in conjunction with a calculated constant percent of total for that time which, multiplied by the measurement taken at the minimum time, will provide a reliable indicator of the total nutrient ion concentration or pH of the soil.

Referring to Figure 5, as noted above, the time required for obtaining a reliable measurement may be minimized by measuring only a percentage of the total nutrient ion or hydronium ion concentration. For instance, Figure 5 shows a typical normalized response time curve of nitrate levels in a clay loam soil. The nitrate ion electrode exhibits similar response time curves for particular soils allowing reliable measurements of a percentage of total nitrate concentration in approximately 4-6 seconds.

Referring to Figure 6, the control subassembly 18 includes a controller 250. Any suitable controller may be utilized so long as it has sufficient input and output lines and processing capability. The inventors have utilized a controller based on the Phillips* 80C552 micro controller. The micro controller uses a microprocessor. As a result, the micro controller is programmable. Output driver circuitry utilizing power field effect transistors (FET's) drive the solenoids and motors. Alternatively, relays could be used to drive the solenoids and motors. Output driver circuitry utilizing relays control a servo motor (not shown) of

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the fertilizer applicator subassembly 20 to open or close a regulating plate on the applicator. Alternatively, output driver circuitry utilizing power FET's could be used for this purpose. An on chip analog to digital (A/D) converter is used for digitizing analog input signals.

Output lines from the controller 250 and output circuitry provide on/off control over the extractant fluid pump 164, the impeller motor 174 (for driving the impeller 172), drain valve 156 through solenoid 157 and standard solution pumps 184, 186. A further output line and output driver circuitry provides on/off control over motor 106 of soil sampling subassembly 12. In addition, two more on/off output lines and output driver circuitry may be connected to hydraulic control means (not shown) to raise and lower the blade 26, motor 32 and housing 34.

The controller 250 is programmed to sequence the various operations in accordance with a pre-determined measurement time T (discussed below) and the time necessary to collect the soil sample.

The controller receives input from the nutrient or pH measurement subassembly 16 and position sensors 260 on the fertilizer applicator subassembly 20 through an analog to digital converter 254. The inventors have utilized the on chip 10 bit A/D converter of the 80C552 micro controller for this purpose. The ground speed sensor 258 is connected to a digital input of the controller 250. The ground speed is determined from the frequency of the digital signals from the ground speed sensor 258. The electric switch 118 is connected to a digital input of the controller 250.

Since the output from the electrode 178 has a high impedance, an amplifier circuit 256 is required to provide impedance matching. Any suitable amplifier circuit 256 may be utilized such as a circuit

constructed using AD822 operational amplifiers (op-amps) as used by the inventors in a preferred embodiment.

Referring again to Figure 1, the fertilizer applicator subassembly 20 will generally comprise any commercially available fertilizer applicator such as, for instance, the Vicon* Super Flow* seeder/spreader. Such applicators are commercially available with ground speed sensors 258 (see Figure 6) and applicator position sensors 260.

In the illustrated embodiment, application rate from the fertilizer applicator subassembly 20 is controlled by means of a servo motor (not shown) which opens and closes a regulating plate on the applicator. Two output lines are connected to relays to control the servo motor. These two output lines open or close the plate depending upon which of those lines is high. The applicator position sensor 260 provides feedback on the position of the regulating plate to the controller 250.

Process steps of the nutrient monitoring system are schematically shown in Figure 7.

Since response time curves of the nutrient or pH measurement subassembly 16 vary depending upon the type of soil being measured, an initial soil calibration step 200 is necessary. A series of measurements are undertaken with samples of the soil which is to be tested. A relatively long measurement time is used in this calibration step so as to ensure that a high percentage of the total nutrient concentration or pH level is measured. As will be understood by those skilled in the art, the number of measurements and the measurement time required for the initial calibration step will vary depending upon the level of certainty required for the measurements being undertaken. Using

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an iterative algorithm, it has been found that 3-4 measurements of a duration of approximately 2 minutes will often provide sufficient certainty levels for reliable soil nutrient concentration or pH level measurement.

Variables calculated in the initial soil calibration step 200 are measurement time T and percent total nutrient or pH constant C. The constant C is the percent of total nutrient concentration or pH level which will be measured with an extraction and measurement time of T within a given confidence level.

The next step 202 is to calibrate the electrodes. Specifically, electric potential of the electrode is related to the nutrient concentration in a soil sample by the Nernst equation:

$$E = E_0 + S \log (A)$$

where, E is the electro chemical cell potential (mV);

E_0 is the standard potential (mV) of a 1M solution;

S is the electrode slope (mV/decade of concentration);

A is the nutrient ion or hydronium ion activity (effective concentration Moles L^{-1} in the solution).

While theoretically the standard potential E_0 and slope S are constant, in practice they vary due to factors such as temperature, the state of the reference electrode filling solution and the condition of the nutrient ion or hydronium ion sensing membrane of the electrode 178. Accordingly, it is necessary to intermittently calibrate the electrode in the nutrient or pH measurement subassembly.

In the preferred embodiment shown in Figure 7, the electrodes are calibrated using standard nutrient (e.g. nitrate) or pH solutions having known molarity.

Two different standard solutions a decade apart (i.e. having a molarity of 0.01 and 0.001 M respectively) are utilized. The standard solutions are stored in calibration solution tanks 24, 25 (see Figure 4). Metering pumps 184, 186 and hoses are adapted to deliver a preset volume of the respective solutions to the container 150 of the nutrient or pH extraction and measurement subassembly 16.

Referring to Figure 8, the calibration routine includes the steps:

(1) 204 - washing the container 150;
(2) 206 - pumping in a preset volume of the first nutrient or pH standard solution;
(3) 208 - commencing rotation of the impeller 172;
(4) 210 - measuring electrode potential until the end point 212 when change in potential over time reaches a preset value indicating that the measured electrode potential is nearing equilibrium;
(5) 214 - storing final voltage reading; and
(6) repeating the process with the second standard nutrient or pH solution.

The electrode slope S is then calculated 216 based on the difference between the measured cell potential E for each of the standard solutions. E_0 may then be calculated for each of the standard solutions and averaging the two values found will give a good approximation of current E_0.

In the illustrated process shown in Figure 7, every twentieth measurement taken by the nutrient or pH monitoring system is of one of the standard nutrient or pH solutions. The frequency of such checks may be varied depending on the particular circumstances. If the measured nutrient ion or hydronium ion activity A is outside a predetermined limit, then the nutrient or pH monitoring system will undertake an electrode calibration routine as described. Prior to entering the

calibration routine, preferably a warning is communicated to the operator of the apparatus since normal measuring will be interrupted for a few minutes.

Measurement of nutrient concentration or pH level in the soil using the nutrient of pH monitoring system includes the steps of:

(1) 218 - starting the soil sampler and pumping a preset volume of extractant fluid into the container;

(2) 220 - after a predetermined time, starting the belt conveyor 100 and impeller 172;

(3) 222 - starting a timer to time the measurement period T;

(4) 224 - measuring electrode potential at time T;

(5) 226 - calculating the nutrient or pH level in the sample using the Nernst equation and multiplying the measured electrode potential at time T by the percent constant C for storage and/or use in controlling a fertilizer applicator;

(6) 228 - opening the valve 156 to drain the soil solution into the drain pipe 158 and cleaning the extractor by spraying extractant fluid and operating the impeller with the valve 156 closed and then opening the valve 156 for draining of the container prior to the next measurement; and

(7) 230 - after every 20 measurements, checking the electrodes using a standard solution to see if they need to be recalibrated.

As is evident from the foregoing, the controller 250 is programmed to operate the nutrient or pH measurement subassembly in three different modes:

1. Soil calibration mode in which the processor is used to calculate the minimum measurement time T and a nutrient or pH percentage constant C for the soil type.

2. Electrode calibration mode in which the subassembly 16 is used to measure electrode potential when standard solutions are being measured to calculate electrode slope S and standard potential E_0.
3. Standard operating mode in which the electrode potential E is measured at time T. The nutrient concentration or pH level of the soil is then calculated using the Nernst equation and the nutrient or pH percentage constant C.

In the first two modes, measurement time is controlled through consideration of the change in electrode potential over time. When the change in potential is at or below a preset minimum, a final measurement is taken. Alternatively, a fixed measurement time (e.g. 2 minutes) can be used. The length of the fixed measurement time depends on the electrode used and the operative conditions.

In the third mode, measurement time T is controlled by the controller 250. Further, the controller 250 may be programmed to control the other subassemblies for intermittent sampling and measuring with delays between sampling being set based on the extent of sampling desired for the particular field or circumstances.

As will be recognized by those skilled in the art, a number of nutrients and pH can be measured at the same time by using multiple containers or in some cases using a single container and multiple ion-selective electrodes for each nutrient and a hydronium ion-selective electrode for pH. The controller could "map" these multiple nutrients and pH or could control the rate of fertilizer based on the nutrient levels and/or pH levels as previously described.

As will also be recognized by those skilled in the art, variations may be made with respect to the specific apparatus and process described and still be

within the scope of the invention as defined in the appended claims.

CLAIMS:

1. A soil nutrient or pH monitoring apparatus for the measurement of nutrient or pH levels in soil samples of a given mass comprising:

(a) a container having at least one opening for serially receiving soil samples and a discharge opening;

(b) a valve selectively operable to open and close the discharge opening;

(c) at least one nozzle for addition of extractant fluid to a soil sample in the container and for addition of cleaning fluid when the soil sample is discharged;

(d) an electro-chemical nutrient or hydronium ion-selective electrode and a reference electrode positioned in the container such that a sufficient portion of each electrode contacts the extract solution formed upon addition of the extractant fluid to the soil sample; and

(e) a controller for controlling the quantity of extractant fluid added to the container so as to ensure proper fluid to soil ratio, for determining the measurement time required to measure the nutrient or pH level of the soil sample, for calculating and recording the nutrient or pH level from the electrodes after the measurement time, and for actuating the valve and nozzle to empty and clean the container after the measurement is completed.

2. An apparatus according to claim 1 wherein the container opening for receiving soil samples is at or near the container's top and the discharge opening is at or near the container's base, the nozzle is positioned over the container, and the controller also controls the

quantity of extractant fluid to ensure that a minimum fill level is attained.

3. An apparatus according to claims 1 or 2 wherein the apparatus further comprises

(a) an agitator associated with the container for agitation of the extractant fluid and the soil sample; and

(b) standard solution storage tanks for discharging standard solutions used in calibrating the electrodes;

and wherein the controller also controls the agitator to mix the soil sample and extractant fluid, controls the intermittent measurement of nutrient or pH levels of the standard solutions, and calibrates the electrodes based on the measurements of the nutrient or pH levels of the standard solutions.

4. An apparatus according to claim 1, 2 or 3 wherein the reference electrode is built into the electro-chemical or hydronium ion-selective electrode.

5. An apparatus according to claim 1 or 2 wherein the apparatus further comprises an agitator mounted in said container for agitation of the extractant fluid and soil sample and wherein the controller further controls the agitator.

6. The apparatus of claim 1 or 2 wherein the apparatus further comprises standard solution storage tanks for discharging standard solutions used in calibrating the electrodes, and wherein the controller controls the intermittent measurement of nutrient or pH levels of the standard solutions, and the controller calibrates the electrodes based on the measurements of the nutrient or pH levels of the standard solutions.

7. An apparatus according to claim 1, 2, 3, 4, 5 or 6 wherein the apparatus is mounted on a farm vehicle for measuring nutrient or pH levels in soil in a field as the farm vehicle traverses the field.

8. An apparatus according to claim 1, 2, 3, 4, 5 or 6 wherein the apparatus is mounted on a farm vehicle for mapping nutrient or pH levels in soil at various locations in a field as the farm vehicle traverses the field and wherein the apparatus further comprises a ground speed sensor wherein the location of each measurement of the nutrient or pH level is also stored in the controller as determined from the ground speed sensor and the time elapsed between each measurement.

9. An apparatus according to claim 1, 2, 3, 4, 5 or 6 wherein the apparatus is mounted on a farm vehicle for mapping nutrient or pH levels in soil at various locations in a field as the farm vehicle traverses the field and wherein the apparatus further comprises a GPS receiver wherein the location of each measurement of the nutrient or pH level is also stored in the controller as determined from the GPS receiver.

10. An apparatus according to claim 1, 2, 3, 4, 5 or 6 wherein the apparatus further comprises a ground speed sensor and a fertilizer applicator subassembly including a fertilizer application rate controller, and wherein the controller actuates the fertilizer application rate controller to apply fertilizer at a rate calculated based upon the ground speed sensor and the measurement of the nutrient or pH level.

11. An apparatus according to claims 10 wherein the apparatus further comprises an application position sensor on the fertilizer applicator subassembly and

wherein the controller applies fertilizer at a rate calculated based also from the application position sensor.

12. A process for rapidly measuring nutrient or pH levels in soil comprising:

(a) Determining a minimum acceptable measurement time by:

(i) Measuring the nutrient or pH level in a reference soil sample at several time intervals over a sufficiently long period of time so that substantially the total nutrient or pH level has been measured by the last interval;

(ii) Calculating the percentage of the nutrient or pH level measured at each time interval by dividing the nutrient or pH level at each time interval by the total nutrient or pH level measured at the last interval; and

(iii) Identifying the minimum acceptable time by determining the earliest time at which the rate of increase in the percentage of the nutrient or pH level measured becomes stable.

(b) Determining the percent total nutrient or pH constant by dividing the total nutrient or pH level at the last interval by the nutrient or pH level at the minimum acceptable measurement time;

(c) Serially measuring the nutrient or pH level in a plurality of test soil samples at the minimum acceptable measurement time; and

(d) Multiplying each measurement obtained in (c) by the percent total nutrient or pH constant.

13. The process according to claim 12 wherein the process is automated for repeated measurements of soil samples in a container and includes the following steps:

(a) Automatically sequentially delivering samples of soil of predetermined mass to the container;

(b) Adding the correct amount of extractant fluid to the container so as to ensure the proper fluid to soil ratio;

(c) Agitating soil and extractant fluid mixture before measuring the nutrient or pH level;

(d) Cleaning the container after each measurement by adding cleaning fluid to the container, agitating the fluid and emptying the fluid from the container between each measurement.

14. The process according to claim 12 wherein the process is automated for repeated measurements of soil samples in a container and includes the following steps:

(a) Automatically sequentially delivering samples of soil to the container;

(b) Determining the mass of each soil sample;

(c) Adding the correct amount of extractant fluid to the container so as to ensure the proper fluid to soil ratio;

(d) Agitating soil and extractant fluid mixture before measuring the nutrient or pH level;

(e) Cleaning the container after each measurement by adding cleaning fluid to the container, agitating the fluid and emptying the fluid from the container between each measurement.

15. The process according to claims 12, 13 or 14 wherein the process includes the step of intermittently calibrating the electrodes by measurement of the nutrient or pH levels in standard solutions.

16. The process according to claim 15 wherein the process includes the steps of measuring nutrient or pH level of a standard solution, comparing the measured level with the known level of the standard solution, and calibrating the nutrient or pH measuring device when the variance between the measured level and known level is above a pre-determined level.

17. The process according to claims 13, 14, 15 or 16 wherein the cleaning fluid is an extractant fluid.

18. The process according to claims 12, 13, 14, 15, 16 or 17 wherein an electro-chemical nutrient or hydronium ion-selective electrode and a reference electrode is used to measure the nutrient or pH levels in soil.

19. The process according to claims 12, 13, 14, 15, 16 or 17 wherein an electro-chemical or hydronium ion-selective electrode with a built in reference electrode is used to measure the nutrient or pH levels in soil.

20. The process in claims 12, 13, 14, 15, 16, 17, 18 or 19, wherein the rapidity of nutrient or pH level measurement is enhanced by use of an unfiltered extract solution comprising soil and an extractant fluid.

21. The process according to claims 12, 13, 14, 15, 16, 17, 18 or 19, wherein the minimum time is less than or equal to 4 seconds.

22. The process according to claims 12, 13, 14, 15, 16, 17, 18, 19, 20 or 21 wherein said nutrient or pH measurement is undertaken using apparatus mounted on a farm vehicle as the farm vehicle traverses a field and

wherein the process includes the step of storing measured nutrient concentrations or pH levels sequentially in a controller to provide a record of nutrient or pH levels as the field is traversed.

23. The process according to claim 22 wherein the process includes the following steps:

(a) determining the location of the farm vehicle from a ground speed sensor and the time elapsed between each said measurement;

(b) storing the location from which the soil samples were taken sequentially in the controller.

24. The process according to claim 22 wherein the process includes the following steps:

(a) determining the location of the farm vehicle from a GPS receiver;

(b) storing the location from which the soil samples were taken sequentially in the controller.

25. A process according to claims 12, 13, 14, 15, 16, 17, 18, 19, 20 or 21 wherein said nutrient or pH measurement is undertaken using apparatus mounted on a farm vehicle as the farm vehicle traverses a field and wherein the process includes the following:

(a) determining the speed of the farm vehicle;

(b) using the calculated nutrient concentration or pH level and the speed of the farm vehicle to control fertilizer application rate of a fertilizer applicator on or towed by the farm vehicle.

26. A farm vehicle mounted soil nutrient or pH monitoring apparatus for mapping nutrient or pH levels in soil in a field as the farm vehicle traverses the field comprising:

(a) a soil sampling subassembly;

(b) a soil transport subassembly;

(c) a nutrient or pH measurement subassembly; and

(d) a control subassembly

wherein the soil sampling subassembly and soil transport subassembly sequentially deliver powdered soil samples of predetermined volume to the nutrient or pH measurement subassembly, the nutrient concentration or pH level of each sample is measured in the nutrient or pH measurement subassembly, and the control subassembly sequences the operation of the other subassemblies and sequentially stores the measured concentrations.

27. An apparatus according to claim 26, wherein said soil transport subassembly includes a conveyor and a soil sample receiving pocket of predetermined volume on said conveyor; and wherein said conveyor is mounted on said farm vehicle to transport said soil receiving pocket between a first position where the pocket is maintained in a spray of soil particles produced by said soil sampling subassembly and a second position where a soil sample collected in said receiving pocket is discharged into a receptacle.

28. An apparatus according to claim 27, wherein the position of the conveyor is controlled by said control subassembly to maintain the soil sample receiving pocket in the spray of soil for a sufficient time to ensure that it is completely filled, and wherein a scraper removes excess soil from the conveyor and soil sample receiving pocket.

29. An apparatus according to claim 28, wherein the conveyor is a belt conveyor, said soil sample receiving pocket is integral with said belt conveyor, said belt conveyor is driven around a roller, said receptacle is located under and adjacent said roller,

and wherein the dimensions of said soil receiving pocket vary as it passes around said roller facilitating essentially complete discharge of the soil sample into said receptacle.

30. An apparatus according to claim 26, wherein the soil sampling subassembly includes a blade mounted on said farm vehicle for rotation about a generally horizontal axis with the blade extending into the soil to produce a spray of soil particles exiting tangentially from said blade upon rotation.

31. An apparatus according to claim 30, wherein said axis of rotation is generally perpendicular to a primary direction of travel of the farm vehicle.

32. An apparatus according to claim 31, wherein said soil sampling subassembly further includes a soil depth controller for maintaining said blade at a predetermined depth in the soil.

33. An apparatus according to claim 31, wherein said blade is mounted on a motor in a housing, said housing having a skid for floatingly supporting said housing on the surface of the soil, and wherein said motor is mounted in the housing such that the rotary cutting blade extends a predetermined distance below said skid.

34. An apparatus according to claim 33, wherein the distance between the skid and the motor may be varied to vary the distance by which the cutting blade extends below the skid.

35. An apparatus according to claim 33, wherein an actuator is mounted on said farm vehicle and connected

to said housing for raising the housing when the soil sampling subassembly is not in use and for floatingly maintaining said blade extending said predetermined distance when in operation.

36. An apparatus according to claim 27, wherein the soil sampling subassembly includes a blade mounted on said farm vehicle for rotation about a generally horizontal axis with the blade extending into the soil to produce a spray of soil particles exiting generally tangentially from said blade upon rotation.

37. An apparatus according to claim 26, wherein said nutrient or pH measurement subassembly further comprises:

(a) a container mounted on said farm vehicle having an opening at or near the container's top positioned to serially receive said soil samples from said soil transport subassembly and a discharge opening at or near the container's base;

(b) a valve selectively operable to close said discharge opening;

(c) one or more nozzle positioned over the container for discharge of extractant and cleaning fluids into the container;

(d) an electro-chemical nutrient or pH ion-selective electrode and a reference electrode positioned in the container such that a sufficient portion of each electrode contacts the extract solution formed upon addition of the extractant fluid to the soil sample;

and wherein said controller controls the quantity of extractant fluid added to the container so as to ensure proper fluid to soil ratio and actuates said valve and nozzle to empty and clean the container after a measurement is completed.

38. An apparatus according to claim 37, wherein an electro-chemical or hydronium ion-selective electrode with a build in reference is used instead of two electrodes.

39. An apparatus according to claims 37 or 38, wherein the apparatus further comprises an agitator associated with said container for agitation of the extractant fluid and soil sample mixture.

40. An apparatus according to claims 37 or 38, wherein said soil transport subassembly includes a conveyor and a soil sample receiving pocket of predetermined volume on said conveyor; and wherein said conveyor is mounted on said farm vehicle to transport said soil receiving pocket between a first position where the pocket is maintained in a spray of soil particles produced by said soil sampling subassembly and a second position where a soil sample collected in said receiving pocket is discharged into a receptacle.

41. An apparatus according to claims 37, 38 or 39 wherein said soil sampling subassembly further comprises a circular blade mounted on said farm vehicle for rotation about a generally horizontal axis with the blade extending into the soil to produce a spray of soil particles exiting tangentially from said blade upon rotation.

42. The apparatus of claims 37, 38 or 39 wherein the apparatus further comprises standard solution storage tanks for discharging standard solutions used in calibrating said electrodes into the container, and wherein said controller controls intermittent measurement of nutrient concentrations or pH levels of

the standard solutions for calibrating the nutrient or pH measurement subassembly.

43. An apparatus according to claim 26 wherein the apparatus further comprises a fertilizer applicator subassembly including a fertilizer application rate controller and a ground speed sensor, and wherein said control subassembly actuates said fertilizer application rate controller to apply fertilizer at a rate calculated based upon input from the ground speed sensor and the nutrient or pH measurement subassembly.

44. A farm vehicle mounted apparatus for obtaining soil samples as said farm vehicle traverses a field comprising:

(a) a soil sampling subassembly including a blade mounted on said farm vehicle for rotation about a generally horizontal axis with the blade extending into the topsoil to produce a powdered spray of soil particles exiting generally tangentially from said blade upon rotation;

(b) a soil sample transport subassembly including a receiving pocket of predetermined volume for receiving a soil sample, a conveyor for transporting the pocket between a first position where the pocket is maintained in said spray of soil particles and a second position where said soil sample is substantially completely discharged into a receptacle; and

(c) a controller for automatically controlling the conveyor to maintain the pocket at the first position for a predetermined duration.

45. The process according to claims 22, 23, 24, and 25 wherein the soil samples are automatically

sequentially delivered to the container using the following steps:

(a) operating a soil sample subassembly to create a spray of soil;

(b) maintaining a soil receiving pocket of predetermined volume in said spray of soil;

(c) transporting the pocket filled with the predetermined volume of soil to a discharge position and substantially completely discharging the sample into the container.

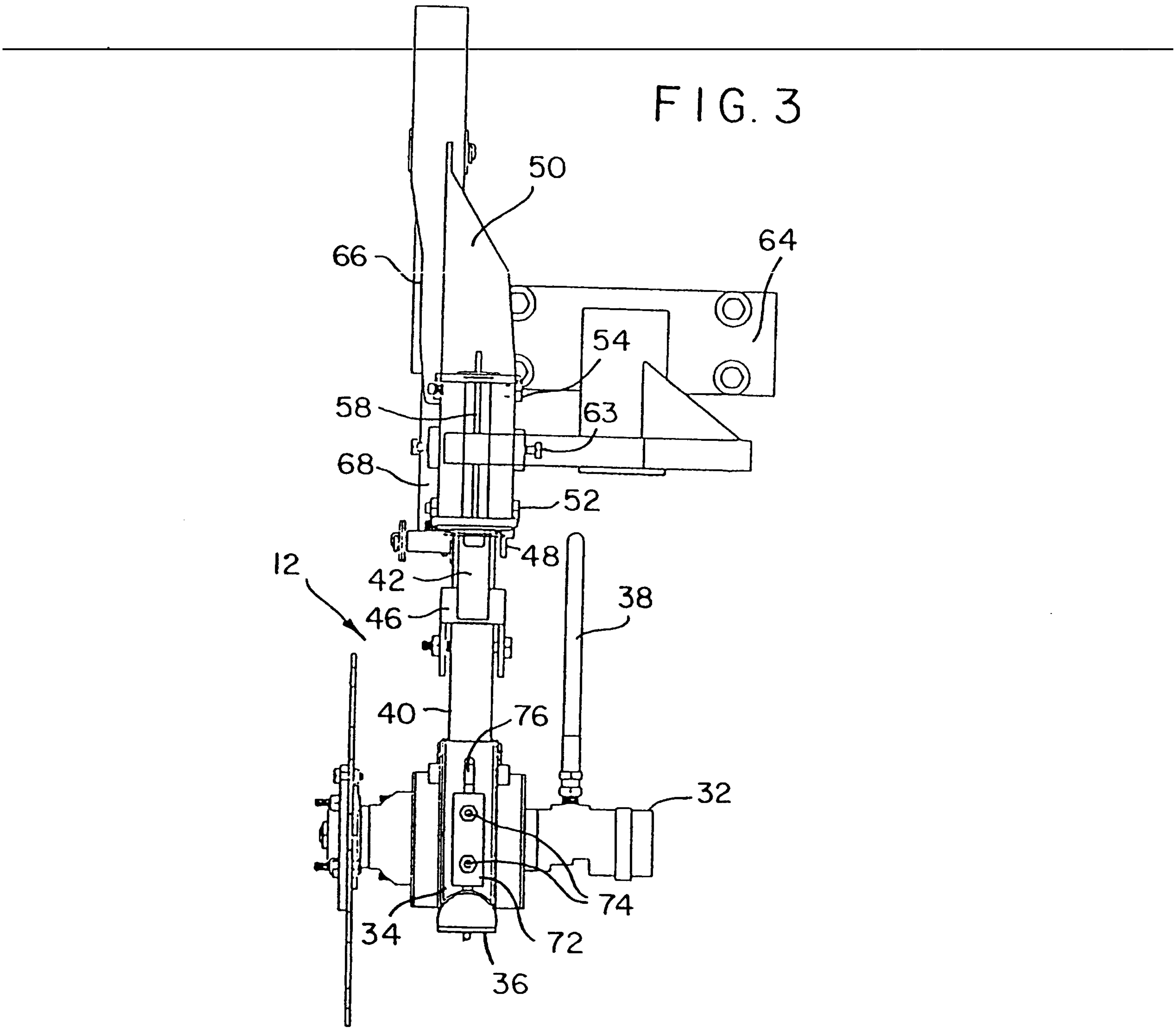
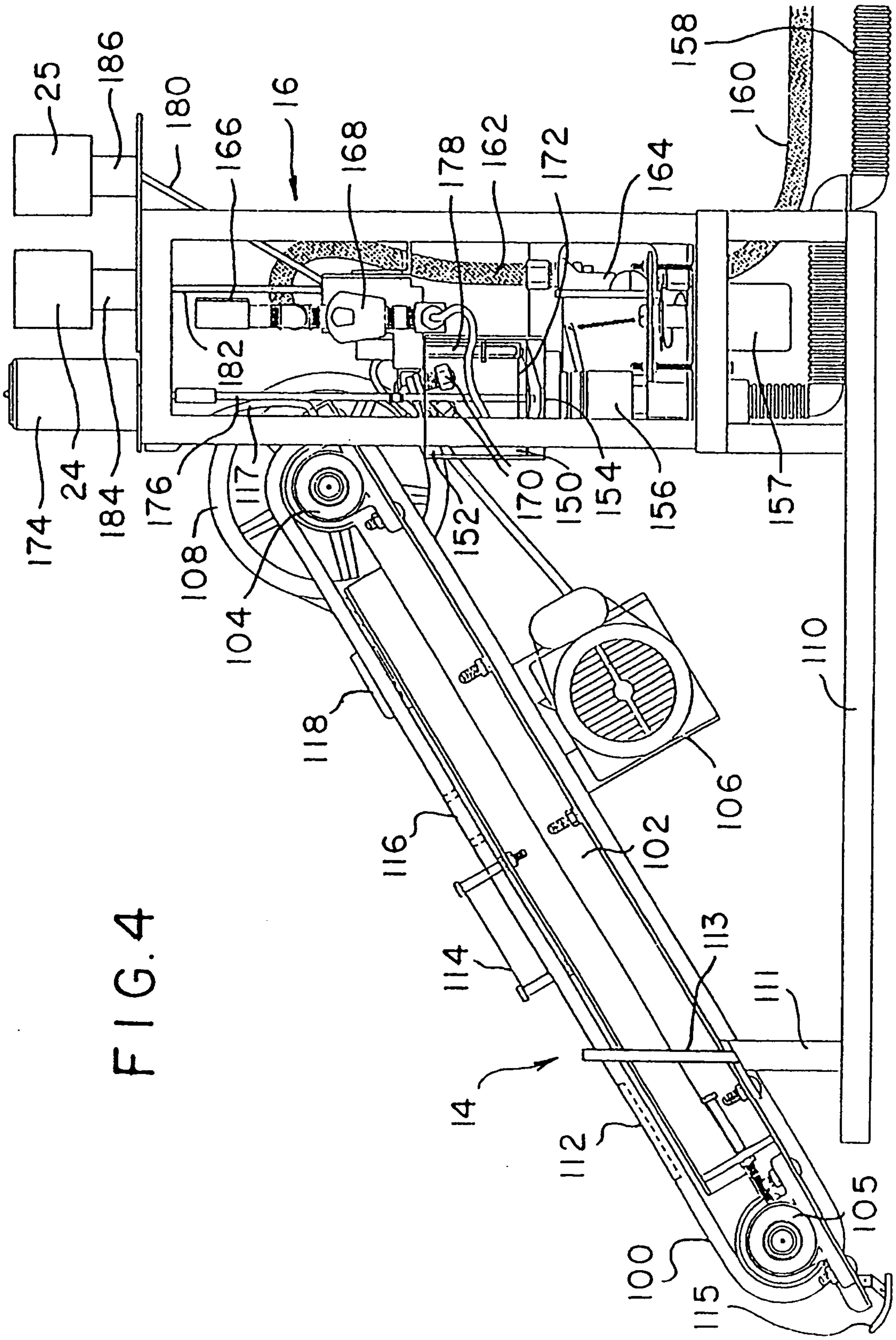


FIG. 3


25
186
180
16
166
168
178
162
172
164
158
160
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24
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176
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170
150
154
156
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106
110
116
102
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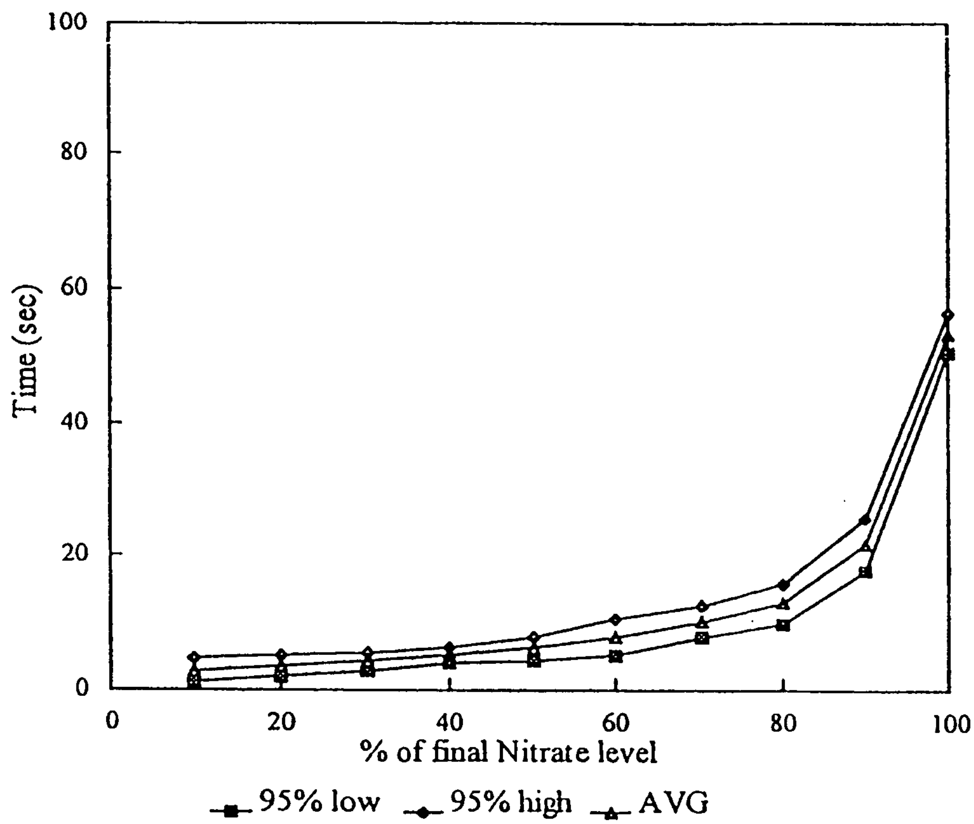
111
14
112
105
100
115

FIG. 4


100
80
60
40
20
0
Time (sec)
0
20
40
60
80
100
% of final Nitrate level
95% low
95% high
AVG

F I G. 5

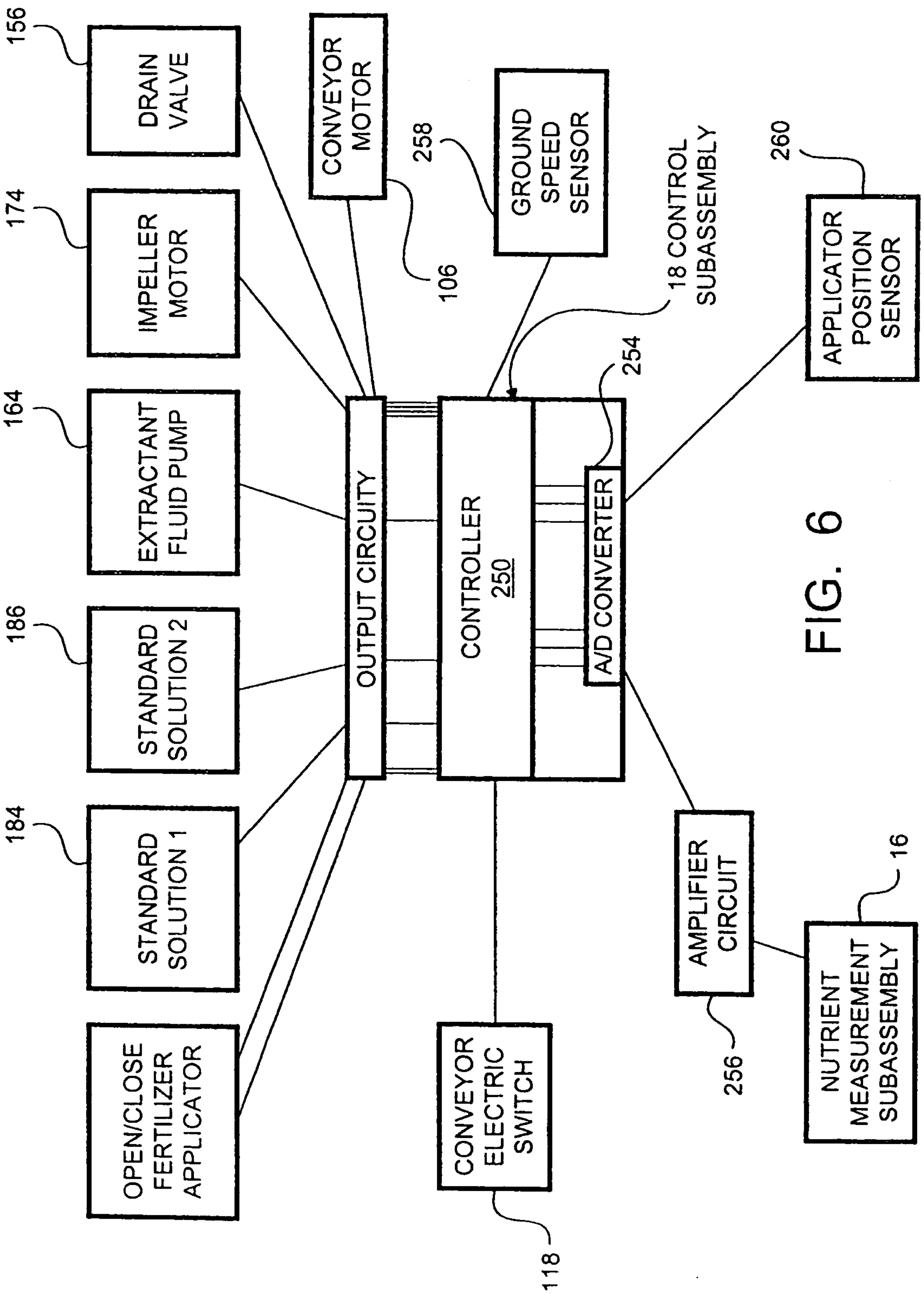

DRAIN VALVE
156
IMPELLER MOTOR
174
EXTRACTANT FLUID PUMP
164
STANDARD SOLUTION 2
186
STANDARD SOLUTION 1
184
OPEN/CLOSE FERTILIZER APPLICATOR
CONVEYOR MOTOR
106
GROUND SPEED SENSOR
258
18 CONTROL SUBASSEMBLY
APPLICATOR POSITION SENSOR
260
OUTPUT CIRCUITY
CONTROLLER
250
A/D CONVERTER
254
CONVEYOR ELECTRIC SWITCH
118
AMPLIFIER CIRCUIT
256
NUTRIENT MEASUREMENT SUBASSEMBLY
16

FIG. 6

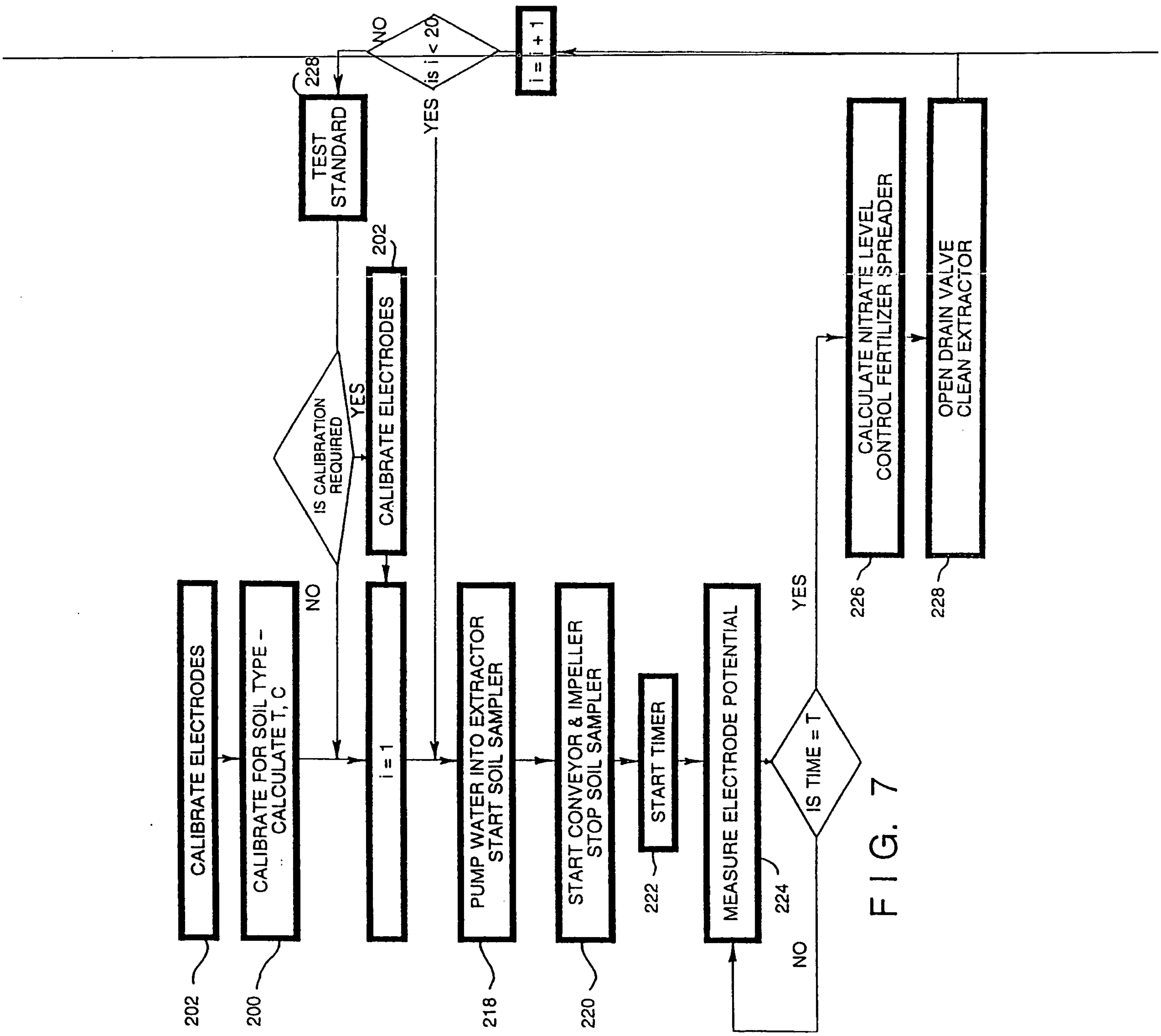

CALIBRATE ELECTRODES
202
CALIBRATE FOR SOIL TYPE – CALCULATE T, C
200
NO
IS CALIBRATION REQUIRED
YES
CALIBRATE ELECTRODES
202
TEST STANDARD
228
NO
is i < 20
YES
i = i + 1
i = 1
PUMP WATER INTO EXTRACTOR START SOIL SAMPLER
218
START CONVEYOR & IMPELLER STOP SOIL SAMPLER
220
START TIMER
222
MEASURE ELECTRODE POTENTIAL
224
IS TIME = T
NO
YES
CALCULATE NITRATE LEVEL CONTROL FERTILIZER SPREADER
226
OPEN DRAIN VALVE CLEAN EXTRACTOR
228

FIG. 7

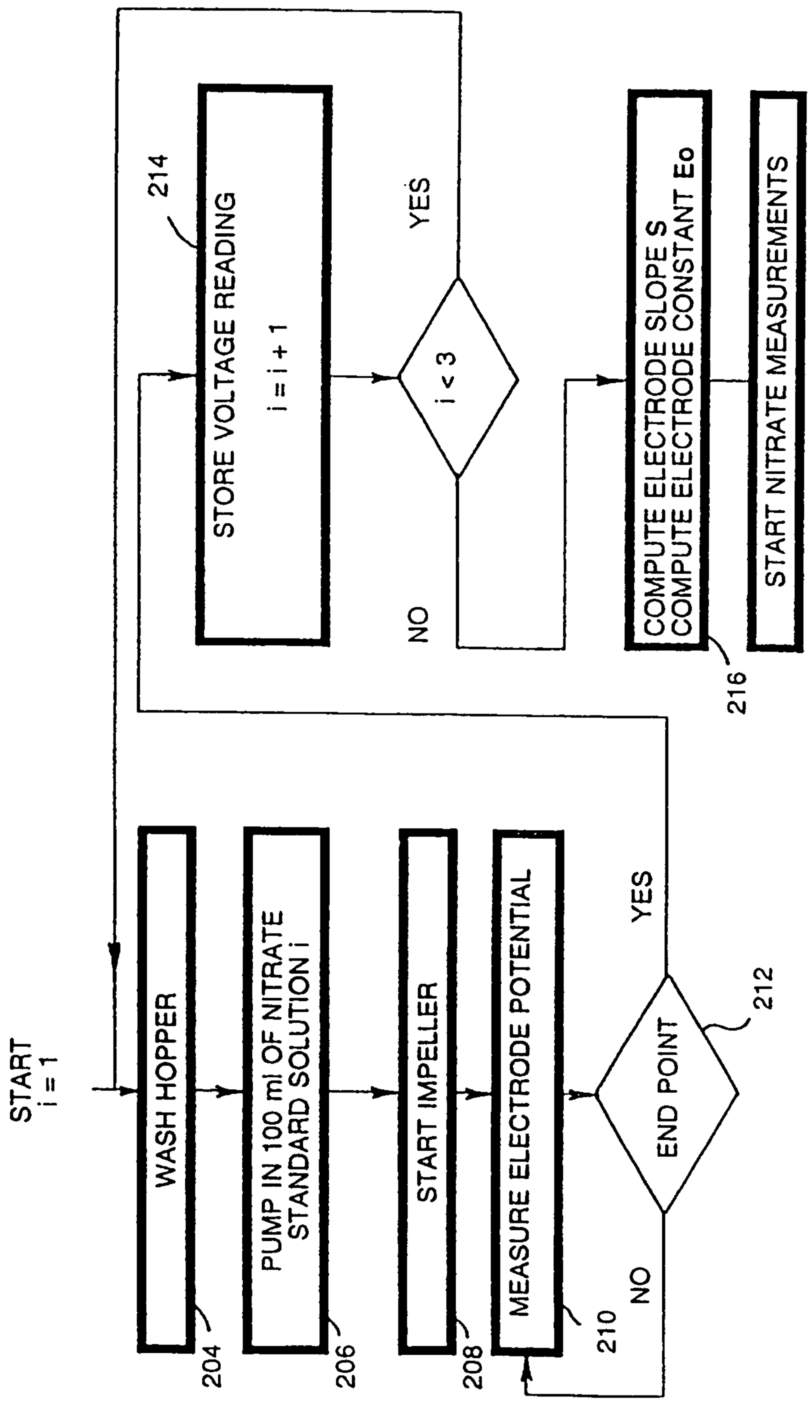

START
i = 1
WASH HOPPER
204
PUMP IN 100 ml OF NITRATE
STANDARD SOLUTION i
206
START IMPELLER
208
MEASURE ELECTRODE POTENTIAL
210
END POINT
212
YES
NO
STORE VOLTAGE READING
i = i + 1
214
i < 3
YES
NO
COMPUTE ELECTRODE SLOPE S
COMPUTE ELECTRODE CONSTANT Eo
216
START NITRATE MEASUREMENTS

FIG. 8

INTERNATIONAL SEARCH REPORT

International Application No
PCT/CA 97/00351

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 G01N33/24 A01C21/00 G01N1/04 A01C17/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 G01N A01C

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5 033 397 A (COLBURN, JR.) 23 July 1991 see column 4, line 53 - column 12, line 32; figures 1-5	1,12,26,44
A	EP 0 370 593 A (AGUILA CORPORATION) 30 May 1990 see page 4, line 7 - page 8, line 57; figures 1-4	1,12,26,44
A	EP 0 615 682 A (AG-CHEM EQUIPMENT CO., INC.) 21 September 1994 see the whole document	1,12,26,44
A	EP 0 116 104 A (ARTHUR YATES AND CO. LIMITED) 22 August 1984 see the whole document	1,12,26,44

-/--

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier document but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
"&" document member of the same patent family

1

Date of the actual completion of the international search	Date of mailing of the international search report
22 January 1998	30/01/1998

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Bosma, R

Form PCT/ISA/210 (second sheet) (July 1992)

International Application No
PCT/CA 97/00351

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 4 869 115 A (EDWARDS ET AL.) 26 September 1989 see the whole document -----	1,12,26, 44

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/CA 97/00351

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
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		DE 69400019 D	02-11-95
		DE 69400019 T	07-03-96
		ES 2079251 T	01-01-96
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